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Copper-Water and Hybrid Aluminum-Ammonia Heat Pipes for Spacecraft Thermal Control Applications

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Abstract

Copper-water heat pipes are commonly used for thermal management of electronics systems on earth and aircraft, but have not been used in spacecraft thermal control applications to date, due to the satellite industry's requirement that any device or system be successfully tested in a microgravity environment prior to adoption. Recently, Advanced Cooling Technologies Inc., (ACT), NASA Marshall Space Flight Center, and the International Space Station office at NASA's Johnson Space Center demonstrated flight heritage in Low-Earth Orbit. The testing was conducted aboard the International Space Station (ISS) under the Advanced Passive Thermal eXperiment (APT_x) project. The heat pipes were embedded in a high conductivity (HiK™) aluminum base plate and subject to a variety of thermal tests over a temperature range of -10 to 38 °C for a ten-day period. Results showed excellent agreement with both predictions and ground tests. In addition, novel hybrid wick aluminum-ammonia heat pipes are developed to handle heat flux requirements for spacecraft thermal control applications. The 5-10 W/cm² heat density limitation of aluminum-ammonia grooved heat pipes has been a fundamental limitation in the current design for space applications. The recently demonstrated 50W/cm² capability of the hybrid high heat flux heat pipes provides a realistic means of managing the high heat density anticipated for the next generation space designs.

Keywords: Copper-water heat pipes; Spacecraft thermal control; International Space Station (ISS); Advanced Passive Thermal experiment (APT_x); Aluminum-ammonia heat pipes; Hybrid high heat flux heat pipes

Copper-water heat pipes are valuable for electronic cooling industry since they offer low resistance thermal transport with operating temperatures in the 300 to 470 K range. As electronics continue to push the envelope on performance, thermal management systems are becoming increasingly more important. Electronics applications frequently require copper-water heat pipes to move heat from discrete components to air heat sinks. High heat fluxes are reduced and heat is moved to open volumes where heat sinks can be located. Heat pipes are excellent for reducing heat fluxes and transporting heat to heat sink hardware. HiK™ plates and copper-water heat pipes are typically used on earth and aircraft applications, but have not been used in spacecraft thermal control applications, since they have never been tested in micro-g environment.

Recently, spacecraft thermal control flight heritage has been demonstrated for copper-water heat pipes and high conductivity (HiK™) plates by micro-gravity testing on the International Space

Station (ISS). This testing was conducted by ACT, NASA Johnson Space Center and NASA Marshall Space Flight Center in the Advanced Passive Thermal eXperiment (APT_x). In the ISS test as shown in Figure 1, the heat pipes were embedded in an aluminum base plate, turning it into a high thermal conductivity plate (HiK™) and subject to a variety of thermal tests over a temperature range of -10 to 38 °C for a ten-day period. Results showed excellent agreement with both predictions and ground tests. The HiK™ plate underwent 15 freeze-thaw cycles between -30 and 70 °C during ground testing, and an additional 14 freeze-thaw cycles during the ISS testing. The following was demonstrated during 10 days of testing on the ISS:

- 1- Successful operation of the copper-water heat pipes and HiK™ plate.
- 2- Ability of the copper-water heat pipes and HiK™ plate to survive multiple freeze/thaw cycles.
- 3- Copper-water heat pipes can carry the required power.

- 4- Copper-water heat pipes and HiK™ plate can start up from a frozen state.

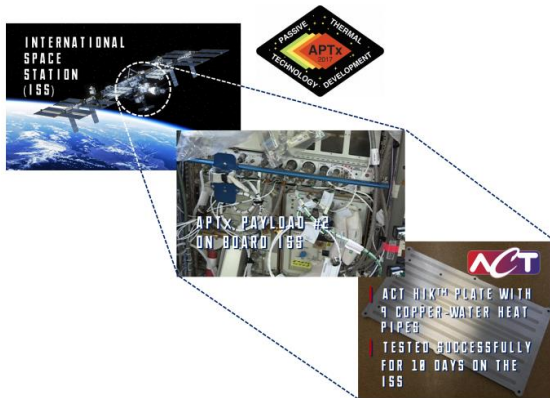


Fig. 1. The HiK™ plate with embedded copper-water heat pipes inside of the International Space Station (ISS).

Grooved aluminum-ammonia constant conductance heat pipes (CCHPs) have been a proven technology for spacecraft thermal control for more than 30 years. However, heat flux limit in these evaporators normally occurs at 5-15 W/cm². In order to increase the heat flux limit to more than 50 W/cm², the concept as shown in Figure 2 is to develop aluminum-ammonia heat pipes with a hybrid wick.

Hybrid wick heat pipes have a porous wick (e.g. sintered wick, screen mesh, or metal foam) in the evaporator section, and a grooved wick in the adiabatic and condenser sections. The porous evaporator wick is capable of operating against gravity on the planetary surface and can also operate at higher heat fluxes. The grooved condenser/adiabatic wick in the hybrid heat pipes allows the heat pipe to operate in space, carrying power over long distances [1].

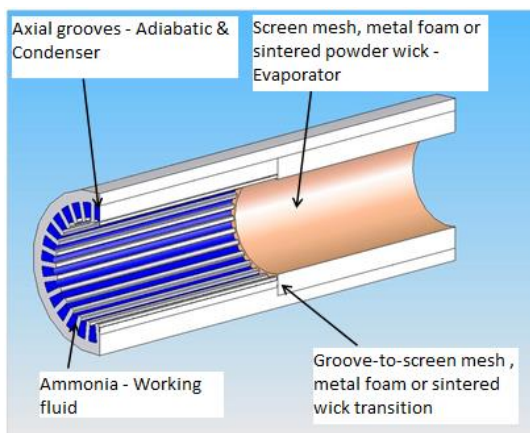


Fig. 2. Hybrid CCHPs: axial grooved adiabatic and condenser sections - screen mesh or sintered evaporator wick.

The high heat flux heat pipe was fabricated as shown in Figure 3, charged with ~ 5 grams of ammonia, and tested.

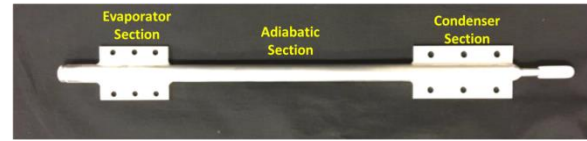


Fig. 3. The second hybrid aluminum-ammonia high heat flux CCHP.

The hybrid heat pipe was tested in horizontal “standard orientation” positions (between 0.1” to 0.3” adverse elevation). **Error! Reference source not found.** shows the thermal performance testing results for the pipe at 0.1” adverse elevation as a function of time.

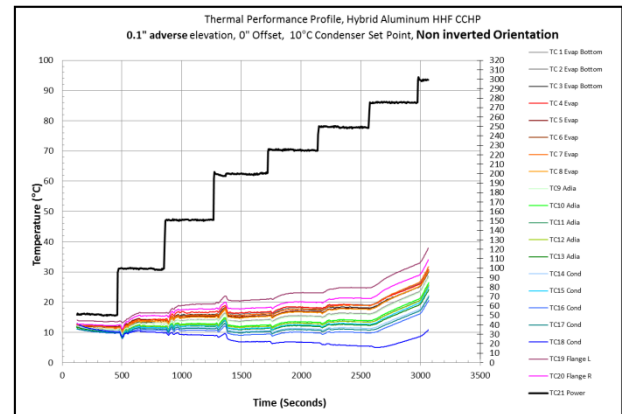


Fig. 4. Thermal performance profile for the hybrid aluminum-ammonia high heat flux heat pipe for 10 °C condenser set point at 0.1” adverse elevation.

The hybrid wick high heat flux aluminum-ammonia CCHP transported a heat load of 275 Watts with heat flux input of 54 W/cm² and R=0.015 °C/W at 0.1 inch adverse elevation. This demonstrates an improvement in heat flux capability of more than 3 times over the standard axial groove aluminum-ammonia CCHP design.

REFERENCES

- [1] Ababneh, M. T., Tarau, C., Anderson, W. G., Farmer, J. T., Alvarez-Hernandez, A. R., and Ortega, S., Advanced passive thermal experiment for hybrid variable conductance heat pipes and high conductivity plates on the International Space Station, 47th International Conference on Environmental Systems 16-20 July 2017, Charleston, South Carolina.